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THE WORK OF HENRI POINCARÉ

WHEN Henri Poincaré, already a member of thirty-five learned societies, was admitted in 1909 to the Académie Française, to the place left vacant by the death of the poet, Sully Prudhomme, M. Masson recounted in the words of a distinguished scientist the career of this master "whose reputation," he said, "is established as an axiom."

"M. Poincaré has a vast mind. He is remarkable both by the diversity and the depth of his knowledge. He is not only a geometer, but also a physicist and an astronomer, not in the fashion of those scientists who give themselves up to observations and experiments, but by the applications he has made of analytic method to science; in other words, he has advanced mathematical physics and celestial mechanics.

"As a geometer, his writings on the theory of numbers, on integral calculus, and on the general theory of functions are spread through more than one hundred and fifty Notes published in the *Comptes Rendus* of the Académie des Sciences, and at least as many articles and memoirs in French and foreign mathematical journals.

"Professor of mathematics at the University of Paris, he has published fourteen volumes of lessons on light, electricity, thermodynamics, and the propagation of heat, making known in France the theories of Maxwell as substantiated by Herz. He has not even neglected wireless telegraphy—an application of the Herzian waves.

"Also on the astronomical side he has shown much originality; there, his studies on the form that a fluid mass takes in rotation and submitted to universal gravitation have led to interesting theories concerning the breaking apart of the earth and moon, and on the formation of diverse variable stars; his work on the stability of the solar system has led, by a revision of the calculus of Laplace and by an approximation pushed still farther, to the proof that the theory as formulated in 1784 is absolutely justified. The three volumes that he has published on celestial mechanics are authoritative amongst astronomers."

In addition, there had also appeared three remarkable volumes[1] in which the philosophic significance of science is studied with rare depth and from which emerges the most profound analysis of knowledge, perhaps, that it may be the good fortune of our age to possess. Yet, in 1913, when four distinguished French scholars unite[2] to review the achievements of H. Poincaré lamentably brought to a close by death on July 17, 1912, much more is still to be told. Not only have significant scientific publications followed those already enumerated, but also another volume of papers[3] of the highest interest to philosophers is added to the list.

Langevin sets forth the dominant characteristics of Poincaré's mind;[4] "His extraordinary power of abstract construction is equilibrated by a constant care for reality; he is a realist in mathematics as in physics. The tree of his thought, branched to infinity, is solidly attached to the soil by deep roots. . . .[5] Henri Poincaré was never troubled by the difficulties of analysis; he knew them scarcely more than nature herself knows them, and he never lost contact with her." If his work lacked unity on the mathematical side it was because he appreciated the adage of Hermite[6]—" 'We are servants rather than masters in mathematics.' . . . The history of the work of Poincaré is nothing else than the history of mathematical science and the problems that it has placed in our epoch." For him science was so much a living thing that growth of a part was not to be distinguished from growth of the whole. No one understood better than he how the solution of a single problem spreads its influence, like the splash of a stone in a pool, until it permeates the whole.[7] "An experiment of Kaufmann on radium revolutionized at the same time mechanics, optics, and astronomy." A discovery by Poincaré in geometry, that "came" while stepping into a 'bus,'[8] has revolutionized our conception of the earth and of the generation of the heavens themselves.

To follow the technicalities that substantiate such work as Poincaré's is a task too difficult for those not deeply versed in the lore of the mathematical and physical sciences. Indeed, even the able expositors of the *"Revue de Métaphysique et de Morale"* frequently impress upon our minds no more than a few baffling phrases—Fuchsian, meromorphic, and thêta functions; curves defined by differential equations, equations with partial derivatives; molecular tensions, capillary attractions, Herzian resonators, convection currents, etc., leaving us scarcely more informed than we were from M. Masson's summary. Yet most of these things have their root in a doctor's thesis of 1879, or the papers that appeared during the next two or three years! And "the accumulation of these memorable works is not their only characteristic. The god who inspired them manifests his impatience in their very style. In a number of them . . . two or three pages, luminous as concise, suffice for the '*veni, vedi, vici*' of a triumph of the human spirit."[9]

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[1] "Science et Hypothèse," 1902; "La Valeur de la Science," 1905; "Science et Méthode," 1907.

[2] *Rev. de Mét. et de Mor.*, September, 1913. L. Brunschvieg, "Le Philosophe"; J. Hadamard, "Le Mathématician"; A. Lebeuf, "L'Astronome"; P. Langevin, "Le Physicien."

[3] "Dernières Pensées," 1913.

[4] *Rev. de Mét. et de Mor.*, *loc. cit.*, page 687.

[5] *Loc. cit.*, page 696.

[6] Hadamard, *loc. cit.*, page 618.

[7] *Sci. et Mét.*, page 310.

[8] *Sci. et Mét.*, page 51.

Throughout we feel the scientist in love with truth and a man of faith, for all scientists "are in a sense men of faith; every passion supposes a faith; every motive of action is a faith; it is faith alone that gives perseverence, that gives courage. But, nevertheless, one is not a scholar if one is not endowed with a critical spirit which seems to exclude every sort of faith and often causes men of science to be taken for skeptics."[10] His conclusions are models of caution. Now he reviews Arrhénius's hypothesis by which the universe might escape that calorific death predicted by Claudius, and concludes that, at most, we can infer a mere retardation of the process; or again he examines cosmological theories only to end in interrogation, since all, including his own, fail to take account of some known fact.[11] Yet M. Poincaré does not lose faith in speculation. Had man been content to await adequate data of knowledge, he would have lacked that imperious curiosity that raises him through science above the savage. This curiosity is the incentive to work and "however well endowed a man may be, it amounts to nothing without work; those who have received the sacred spark from heaven are no more exempt than the others; their very genius only cuts out their work for them."[12]

It is, however, M. Poincaré's reflections on the nature and significance of science that especially concern the philosopher, for he has rare acumen and an acquaintance with the subject-matter with which he deals such as is almost unique in our literature. There have been as keen philosophers and as learned scientists, but, with the exceptions of Aristotle, and possibly Leibnitz, such intensity of philosophic interest and scientific creativeness have never before been united in one man. The unwary reader, however, should be warned that from the appearance of "Science et l'Hypothèse" in 1902 to that of the "Dernières Pensées" in 1913 there is manifest an unfolding of the results of analysis that often betrays the unprepared, for it is easy to pigeon-hole his earlier works as an expression of a phenomenalistic relativism that is far from their real import.

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[9] *Rev. de Mét.*, pages 634–35.

[10] "Savants et Ecrivains," page v.

[11] Leçons sur les Hypothéses Cosmogoniques," 1911–13.

[12] "Savants et Ecrivains," page iv.

"For the superficial observer," "Science and Hypothesis" begins, "scientific truth is beyond the possibility of doubt; the logic of science is infallible, and if the scientists are sometimes mistaken, this is only from their mistaking its rules." When we look a little more closely this confidence vanishes. We find the scientist everywhere depending upon assumptions and these assumptions are by no means as stable as one might think. It is not a question of such simple outlived ideas as defined for antiquity the shape of the earth or the movement of the heavenly bodies, but of Carnot's principle, of the principle of the relativity of space, or Newton's principle of the equality of action and reaction, of Lavoisier's principle of the conservation of mass, and even of Mayer's principle of the conservation of energy. We can not as yet predict the outcome in particular instances, but such present doubts illustrate the instability of the most fundamental certainties that science can contribute to our knowledge.

What shall we do? Deny everything? "To be skeptical in this fashion is still to be superficial. To doubt everything and to believe everything are two equally convenient solutions; each saves us from thinking."[13] But a superficial acquaintance with the results of science convinces us that even our discarded hypotheses have been useful. New science, then, if it is to transcend our present science, must keep alive something of it or our old science will persist by the side of it. Our formulæ are like the victims of Kipling's vampire, for some of them live, though most of them die, and it is experiment alone through which these things are found out. But M. Poincaré is fond of pointing out that experiment is not everything unless it be understood to be something more than a mere quest of observations. The observations must be used, and to be used they must be generalized. Carlyle's love of mere fact was unworthy of a countryman of the man who invented the phrase *experimentum crucis.* No heap of facts constitutes science, but rather an organization of facts. It is science that enables us to predict, and a single observation by a wise scientist like Pasteur can tumble into oblivion all the crowd of facts a lesser mind might amass in a lifetime. Bacon would have understood this, but not Carlyle. At best experiment gives us only a number of isolated points. To reduce these to law we must join them by a continuous line, but "the curve we trace will pass between the observed points and near these points; it will not pass through the points themselves. Thus we do not restrict ourselves to generalizing the experiments, but we correct them; and the physicist who should try to abstain from these corrections and really be content with the bare experiments would be forced to enunciate some very strange laws."[14]

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[13] "Science et l'Hypothèse," page 2.

Even mathematics is not exempt from this dependence upon fact. M. Poincaré seems never to weary of returning to attack the logicians, of whom B. Russell and Hilbert are leading representatives, when they would found mathematics on arbitrary definitions and postulates. The first chapter of "Science and Hypothesis" demonstrates the factual foundation of arithmetic, the second of geometry; the "Value of Science" begins with a discussion of the respective rôles of intuition and logic in mathematics; the second part of "Science and Method" recurs to the same problem and ends with the words, "the old logistic is dead, so much so that already the zigzag theory and the no-classes theory (Russell) are disputing over the succession"; and chapters three, four, and five of the "Dernières Pensées" are at the problem again, emphasizing especially the conclusion that "there is no logic or epistemology independent of psychology."[15]

Mathematical propositions are, then, transcriptions of experience. It may be of psychological experience, such as our right to repeat a certain process indefinitely—the principle of complete induction—or of the conditions of movement which affect our geometrical interpretations of space; or again, they may express complex relations among physical objects, and often both psychological and physical experiences are invoked.[16] Incidentally he has contributed to the solution of the problem of the non-Euclidean geometries for the philosopher by showing that every one of their theorems is useful to solve problems of Euclidean geometry, thus extending the significance of Reimann's and Beltrami's proof that any fact expressed in Euclidean terminology could be expressed by any non-Euclidean system, and *vice versa;* and also the problem of hyperdimensional geometries similarly by showing that any equations expressing facts of space in terms of three dimensions can be translated into equations expressing those same facts in terms of N-dimensions, although, of course, the dimensions would not remain the same entities (lines). The consequence is that geometries are only languages and our choice of geometries is based merely on convenience.

But this does not mean that the choice is arbitrary. "It is true that it is convenient, it is true also that it is convenient not only for me, but for all men; it is true that it will remain convenient for our descendants; it is true finally that this can not be by chance." The reason is that "all that the scientist creates in a fact is the language in which he enunciates it" and "scientific fact is only brute fact translated into a more convenient language."[17] Consider the four following statements of fact. They are M. Poincaré's freely transcribed. It is getting dark, says the man on the street; an eclipse is taking place, says the astronomer; the eclipse is a phenomenon that could have been deduced from tables derived from Newton's laws, says a mathematician; and the cause of it is that the earth revolves around the sun, says Galileo. All of these statements transcribe the same fact of experience. The first denotes a present experience in relation to what has just been experienced; the second relates a present experience to the great mass of past and future experiences; the third appeals to our powers of predicting and concatenating events; and the last is so stated that one who is sufficiently informed can see that Newton's tables are possible to construct and of guaranteed applicability to this present experience.

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[14] "Science et l'Hypothèse," Ch. IX.

[15] "Dernières Pensées," page 139.

[16] *Cf.* "Why Space has Three Dimensions," "Dernieres Pensées," Ch. III.

The purpose of our theories, accordingly, is not to describe things as they really are. They are not based on experience alone, but spring from a collaboration of intellectual activity and facts whose status is imposed by practical life. Their durability lies in their power to simplify and unify the relations between things, and their ephemeral aspect in their descriptive implications. When astronomers said that the earth was the central body about which the sun and stars revolved, they were saying nothing false except in so far as they might be taken as speaking descriptively. That is, if we look upon their theory merely as a formulation of certain relations that express themselves among visible objects in the open heavens and the visible earth, we find that it is a simple and unifying formula by which to record them. To the casual observer, the sun, moon, and stars *do* pass as they might if they revolved about the earth. The motion is a fact. The trouble comes when we look more closely and observe regressions and variations from the motion that is at first the only one apparent to the eye. We must then reconstruct our theory, and only then do we find that the helio-centric hypothesis has much more power to unify and simplify than the other, and we say it is true in a deeper sense. Naïvely we chose the most conspicuous objects and scientifically those simplifying the most expressions. The naïve statement is not false, but an awkward conveyance of truth.

This is the essence of Poincaré's identification of the truth with the convenient. In his last volume[18] he explicitly identifies the conception with pragmatism and elaborates the conception as implying that every statement that has a meaning must lead to some consequences verifiable in fact, and that in this consists its truth. Abstractions can be nothing but short cuts to getting into working relations with the concrete. Unfortunately, the issue is confused for the philosopher by an identification of pragmatism with idealism, and the opposed school, characterized as Cantorians, with the realists. These realists are more of the scholastic than of the modern type. Their realism is based on essences and universals, and on things outside of relations to human beings, but of which the true and the false may be uttered, although it is inconceivable that such utterances meet with verification or rejection. They live by definition through *genus proximum et differientiam specificam* and discover the geometrical entities they define, instead of defining those that they discover.

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[17] "La Valeur de la Science," Ch. X.

[18] "Dernières Pensées," pages 136 seq.–146 seq.

M. Poincaré's idealism accords verbally with traditional statements, "an object exists only when it is thought" and "an object can not be conceived independently of a thinking subject," as opposed to the realistic, "the world existed before the creation of man, even before living beings; it would exist even if there were no God or thinking subject." But the general character of his epistemology and ontology puts us in a curious dilemma in interpreting these statements. Either this scientist, whose thinking is most exact in the field of science, experiences an astounding lapse of logical intuition when he enters the realm of philosophy, or else his idealism must be read without those Berkeleian connotations the above quoted idealistic phrases usually carry with them. In favor of the first conclusion is the curious Pythagoreanism by which he defines the objective as that which is common to many minds, and concludes that consequently it can be nothing but mathematical relations, on the ground that while the identity of sense qualities in two observers can not be established, the scientific equivalents of them, the mathematical relations involved in their experience, can be.

On the other hand, in an essay contributed to a volume entitled "La Matérialisme Actuelle"[19] and in the sixth chapter of the "Dernières Pensées" he favors an atomistic and discontinuous account of a deterministic universe that seems quite independent of human consciousness. A definite solution of this problem of interpretation can not be given without knowledge of the theory of consciousness which must underlie these statements, and this M. Poincaré has nowhere given us. If, for example, such a theory had been developed along the lines of the new behaviorism, the statement that the world can only exist in the mind of a thinking being would mean that the world, as man knows it, is merely an organization of objects thrown into a practical perspective by their relations to the possible modes of activity latent in the human or animal organism and, in connection with epistemology, that objects are only aspects of an ultimate, isolated (made objects) by these demands for action. On the other hand, a representative theory of consciousness would lead to an orthodox Berkeleianism difficult to harmonize with the ontology and epistemology. The evidence left us is so slight that it would be illegitimate to conclude in favor of either interpretation.

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[19] Paris, 1913; contains also essays by Bergson and others.

When we examine the character of the formulæ by which we express our knowledge, we find three distinct types. First, there is a class of verifiable propositions of the sort that lead experimentally either to verification or to refutation. In either case they are useful, for, if immediately rejected, the false ones at least narrow the field of investigation and the very experiment which rejects them may suggest a new hypothesis to replace the old, and thus be a great aid to discovery, because when an hypothesis that pretends to take into consideration all the factors in a given situation fails, it can only mean that some unknown factor is present, something unexpected and extraordinary which, without the false hypothesis, might have been a long time overlooked.

The second class of hypotheses consists of general statements that are useful to us in fixing our ideas, but which can not be submitted to experimental tests and so can not be affirmed or denied. The principle of the conservation of energy is such an hypothesis. The only condition that makes it true is that we enunciate it for a strictly isolated system, but this condition can never be realized in a system upon which experimental observation is possible. Yet it is of the highest value, for it expresses something that a large number of scientific laws have in common. Its very generality guarantees its unverifiability. But if the principle has a meaning, may it not be false? It may well be that we have not the right to apply it indefinitely even though it is certain to be verified in the strict sense of the term. We shall know when we have reached the limits of its applicability by the fact that it ceases to be useful in the prediction of new phenomena and it will stand condemned without being contradicted.

The third class of hypotheses are such only in appearance. They are really what M. Poincaré calls disguised definitions or conventions. "These conventions are the work of the free activity of our mind, which, in this domain, recognizes no obstacle. Here our mind can affirm since it decrees, but let us understand that while these decrees are imposed upon our science, which without them would be impossible, they are not imposed upon nature. Are they arbitrary?

No, else they were sterile. Experiment leaves us our freedom of choice, but it guides us by aiding us to discern the easiest way. Our decrees are, therefore, like those of a prince, absolute but wise, who consults his counsel of state.''

The discovery of an hypothesis is an interesting case of creative imagination and M. Poincaré has contributed an important chapter to the psychology of this problem. Certain of the dominant factors of discovery are possessed by every one. In the first place the creator must be able to reason; in the second, he must be able to remember, and in the third, he must possess a certain sensibility less easy to define. All men should be able to understand mathematics, for all men go through the same thought processes as the mathematician, but some men can not remember mathematical facts surely enough to retain long series of mathematical reasonings, just as some men can not retain the dominant facts in a game of chess well enough to be good players. But the last factor of creation is by no means common to all. In discovery, there is presented to thought countless combinations from which those most likely to fit the situation in question are selected, but the creative act is not merely one of selection, for to the real creator many combinations are not even presented. Only the useful ones present themselves, or at least those that have a fragmentary utility that may be rejected later as inadequate. A long period of fruitless work often precedes, rejected combination after rejected combination, then suddenly, at a quite irrelevant moment, such as in the midst of a conversation, or a walk, the proper idea appears with a strong feeling of illumination and certainty that can only be justified or refuted by later work. Unconscious work has evidently been taking place. But M. Poincaré is loath to accept this as evidence of a subliminal self as a causal factor while any other plausible hypothesis remains. What may happen is that an automatic combining and recombining takes place until certain combinations having a peculiar affinity for our emotional consciousness occur and bring themselves to our attention. The most original part of his discussion is the interpretation of this feeling as esthetic, a feeling of ''the harmony of numbers and forms, of geometric elegance,'' and there have never been finer pages written than those following on the relation of the beautiful and the useful; for not only is the sense of harmony the determining cause in the selection of facts and scientific creation, but it is also the instigator of the endeavor from which results that flash of intellectual light which is the essence of man's brief terrestrial career.

''The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful. . . . Of course I do not here speak of that beauty which strikes the senses, the beauty of qualities and appearances; . . . I mean that profounder beauty which comes from the harmonious order of the parts and which a pure intelligence can grasp. This it is which gives a body, a structure, so to speak, to the iridescent appearances which flatter our senses, and without this support the beauty of these fugitive dreams would be only imperfect, because it would be vague and always fleeting. . . . And we need not fear that this instinctive and unavowed prepossession will turn the scientist aside from the search for the true. One may dream a harmonious world, but how far the real world will leave it behind! The greatest artists that ever lived, the Greeks, made their heavens; how shabby they were beside the true heavens, ours!

"And it is because simplicity, because grandeur, is beautiful, that we preferably seek simple facts, sublime facts, that we delight now in following the majestic course of the stars, now in examining with the microscope that prodigious littleness which is also a grandeur, now in seeking in geological time the traces of a past which attracts because it is far away.

"We see, too, that the longing for the beautiful leads us to the same choices as the longing for the useful. . . .

"Whence comes this concordance? Is it simply that the things which seem to us beautiful are those which best adapt themselves to our intelligence, and that consequently they are at the same time the implement this intelligence knows best how to use? Or is there here a play of evolution and natural selection? Have the peoples whose ideal most conformed to their highest interests exterminated the others and taken their place? All pursued their ideals without reference to consequences, but while this quest led some to destruction, to others it gave empire. One is tempted to believe it. If the Greeks have triumphed over the barbarian, and if Europe, heir of Greek thought, dominates the world, it is because savages loved loud colors and the clamorous tones of the drum which alone occupied their senses, while the Greeks loved the intellectual beauty which hides beneath sensuous beauty, and it is this intellectual beauty that makes intelligence sure and strong."[20]

The "Dernières Pensées" gives us our only glimpse of Poincaré's moral philosophy,[21] and much of the discussion here is limited to the relations between science and morals. Morality for Poincaré is ultimately based on feelings, hence there can be neither a scientific morality nor an immoral science. Science can help us to foresee what consequences follow if we act in a certain fashion. It can also cultivate our sense of harmony and our love of truth. It can develop habits of generalization so that we can see the furthering of our personal interests as subordinate to wider interests, but it can not prove a moral law and must contradict our idea of liberty, except in the sense in which Fouillée construes this idea itself as a moving force. Half science only is dangerous, for facts remain what they were before they were articulated in scientific language. The power of morality can not be weakened by an understanding of its secret force: "Is gravitation less irresistible since Newton?" Life presents itself as a strife in which now this and now that triumphs, and moral education consists in organizing this strife to make as efficient as possible our energies which are, in this relation, our feelings.

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[20] "Science et Méthode," Ch. I.

[21] *Loc cit.*, Ch. VIII., "La Morale et la Science"; Ch. IX., "L'Union Morale."

And the popular attitude toward science, as expressed by the appropriations of governments, recognizes its ideal value. Astronomy is one of the most expensive of the sciences, from the point of view of research, yet governments never hesitate. And how is astronomy useful?[22] It raises us above ourselves and makes us conscious of our power through its eternal presentation of harmony and law. It is a prototype for our analysis of matter. "The stars send us not only that visible and gross light which strikes our bodily eyes, but from them also comes to us a light far more subtle, which illuminates our minds. . . ." Astronomy taught man that there are laws from which he can not escape, and with which there is no possible compromise. It has taught him also the essential character of law, for from Newton he first learns that law is a necessary relation between the present state of the world and its immediately subsequent state. It has also taught us to set aside appearance. "The day Copernicus proved that what was thought the most stable was in motion, that what was thought moving was fixed, he showed us how deceptive could be the infantile reasonings which spring directly from the immediate data of our senses." It has freed us from the illusion that the world is made for man and it has taught us not to fear big numbers. It may be that the stars will become a "majestic laboratory" and "gigantic crucibles" for the chemist; "perchance, even, the stars will some day teach us something about life." Indeed, Poincaré is fond of repeating, it is astronomy that "has made us a soul capable of comprehending nature."

The value of science does not, then, rest in any material achievement in a utilitarian sense, and it is not a mere servant of man through which he attains a dull mastery of an existence which he can subject to his caprice, but science is rather the assertion of that cosmic law through which man becomes more finely molded than the beasts. And everywhere it is mankind, and not men, that truly succeeds, and truth, in the legitimate sense of the abstraction, rather than loved truths. "Just as humanity is immortal, although men suffer death, so truth is eternal, although ideas perish, because ideas beget ideas as men beget men."[23]

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[22] "La Valeur de la Science," Ch. VI.

HAROLD CHAPMAN BROWN.

COLUMBIA UNIVERSITY.

MUSIC AND EMOTION

THE esthetic emotions have long figured as one of the least understood parts of the subject-matter of psychology. Psychologists have called these emotions "pseudo-emotions." And, after bestowing upon them such an uncomplimentary title, they proceed to admit that upon the whole "they are something of a mystery." The name, "pseudo-emotion," seems to imply a suspicion that the arousal of emotion through the arts is in some sense not quite normal. Works of art are contrasted with ordinary stimuli as "artificial" to "natural" stimuli. However, when one recalls the age-long alliance between music and the dance, between music and religion, and between music and song, such a contrast seems to be inappropriate. The universality with which music is utilized as a means of man's self-expression would afford indication of the accommodation of the organism to such stimuli. The writer is convinced that, at bottom, music (and all the other arts, for that matter) rests upon the exploitation of that sort of exciting agency which is the "natural," innately appropriate, and adequate stimulus for the calling forth of an emotion through the excitation of the sense-organs. In this paper I wish to undertake to throw some little light upon the connection of music and emotion. The mechanics of the correlation admit of a certain amount of explication. I must preface my remarks, however, with the admission that I can offer little more than suggestions of the direction in which research, I believe, might profitably proceed.

The point of difficulty in understanding the connection of music and emotion is not the general fact that music arouses emotion, but the necessity of finding specific differences in the music-stimuli to account for the specific differences in the various emotions aroused. Air-vibrations seem to be a most colorless medium. That mere air-vibrations should form an exciting agency for the whole gamut of human feelings, its martial ardors, its loves and hates, its joyances and sadnesses, is truly an astounding fact! Equally astonishing in their own way, doubtless, are the effects of pigment and pencil, marble and bronze, and the word-jewelry of the poet. But the medium of music apparently is so diaphanous and intangible, and its

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[23] "Savants et Ecrivains," page 175.